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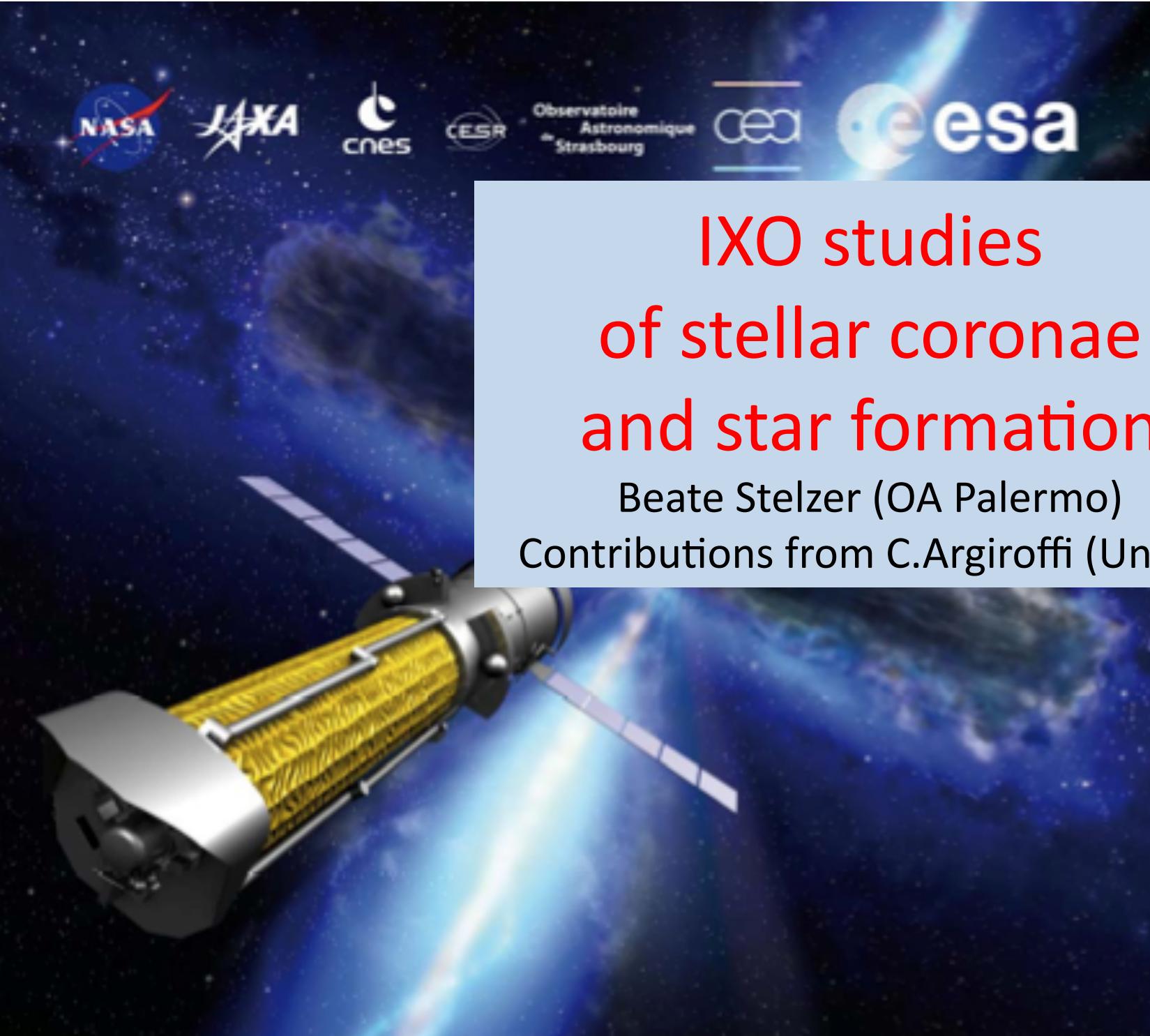
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IXO studies of stellar coronae and star formation

Beate Stelzer (OA Palermo)
Contributions from C.Argiroffi (UniPa)



Stellar science with IXO

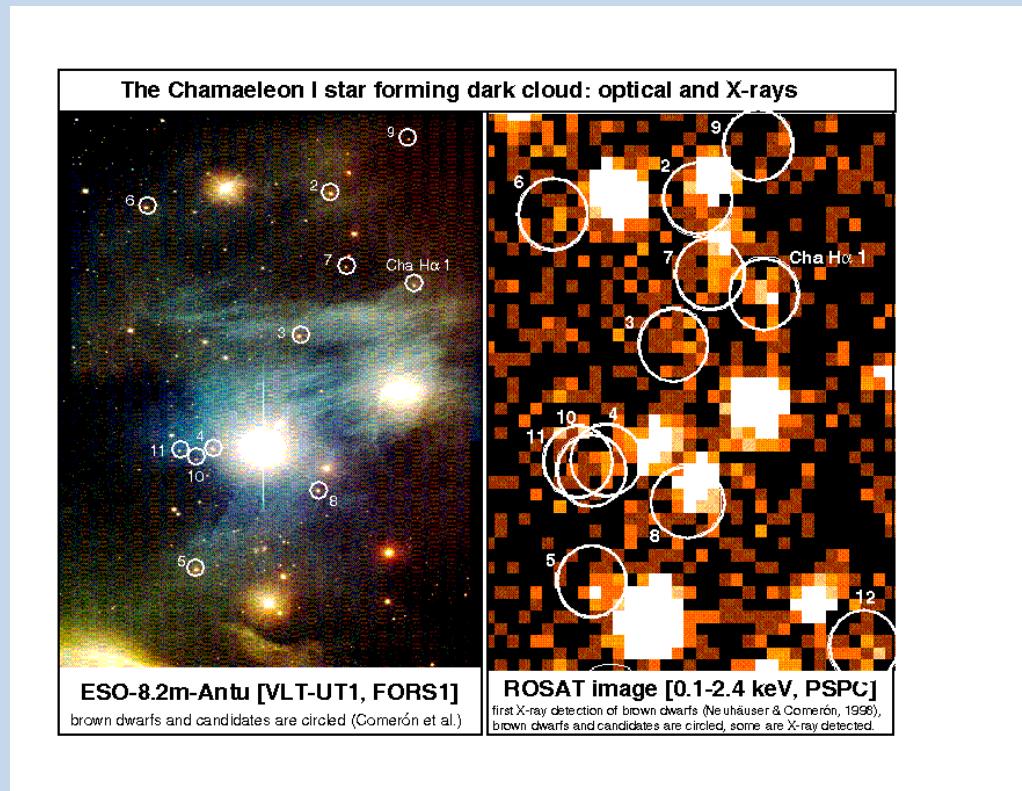
Topics of this talk:

- Origin of the X-ray emission from brown dwarfs
- Accretion onto young stars (+ brown dwarfs)
- Nature of the Fe K α emission in pre-main sequence stars

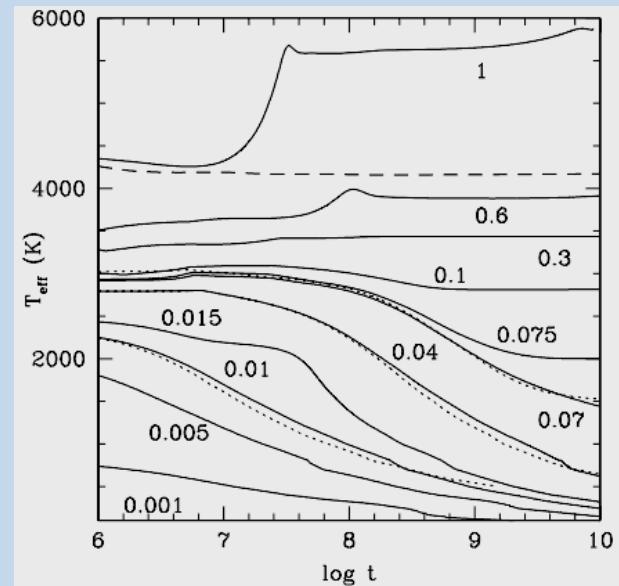
X-rays from brown dwarfs

1st X-ray detection of a brown dwarf with ROSAT in Cha I (Neuhäuser & Comerón 1998, Sci 282):

- young BDs are brighter (in X-rays) than old BDs [if $L_x/L_{bol} \sim \text{const.}$]
- star forming regions are crowded → need spatial resolution



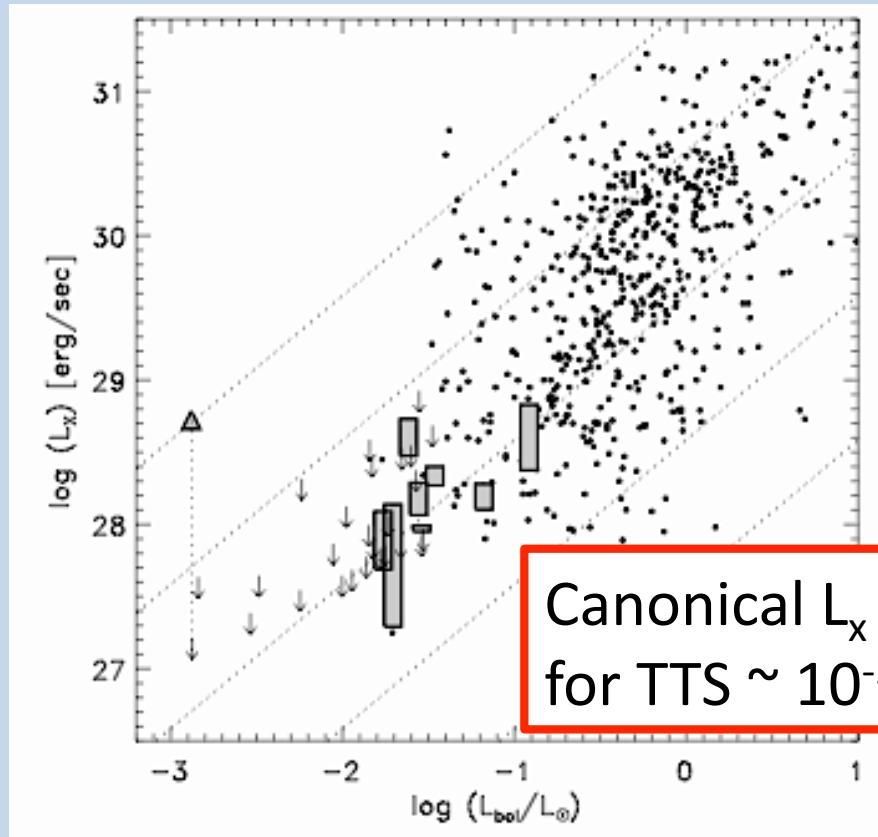
BD cooling curves (Chabrier & Baraffe 2000)



- Are young BDs substellar analogs to T Tauri stars?
- How does X-ray emission (dynamo) of BDs evolve with age?

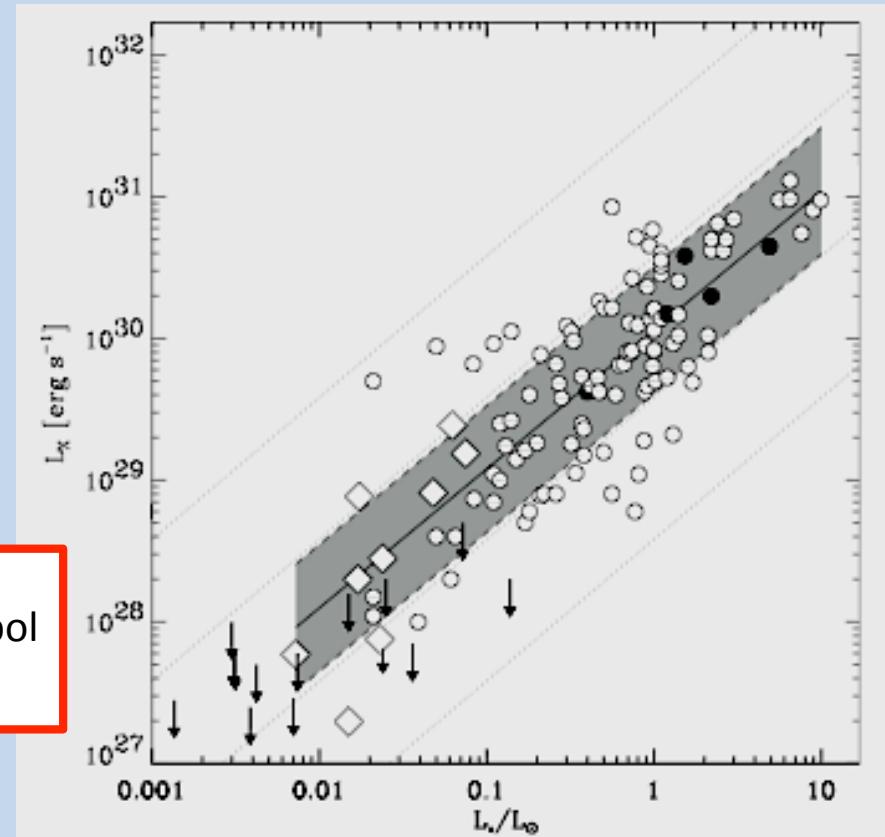
Brown dwarfs: Dynamo in the substellar regime compared to TTS?

COUP (ONC) -- 1 field for 850ks Chandra



Preibisch et al. (2005)

XEST (TMC) -- 19 fields for 30 ks XMM



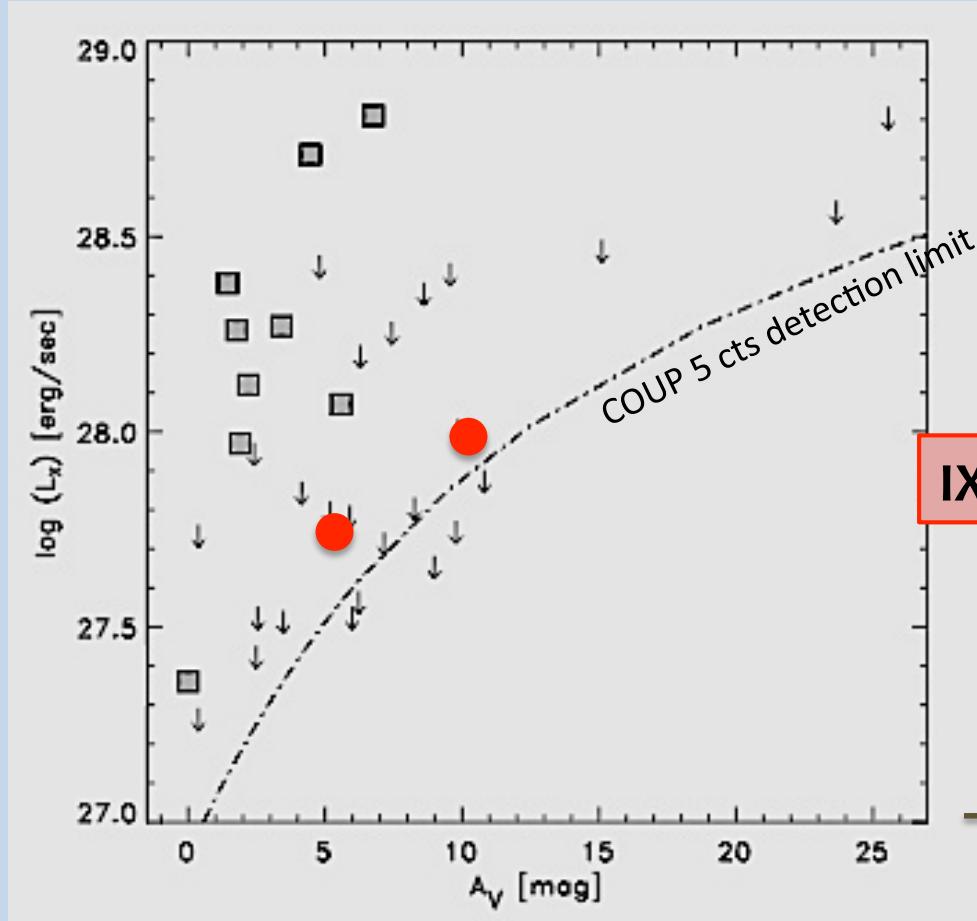
Grosso et al. (2007)

Is L_x / L_{bol} of BDs in star forming regions comparable to higher-mass stars or lower ?

Currently too few BDs are detected in X-rays.

Detecting brown dwarfs with IXO/WFI

COUP: 850ks Chandra in Orion
→ Only weakly absorbed BDs detected



Preibisch et al. (2005)

Assume a strongly absorbed BD in ONC:

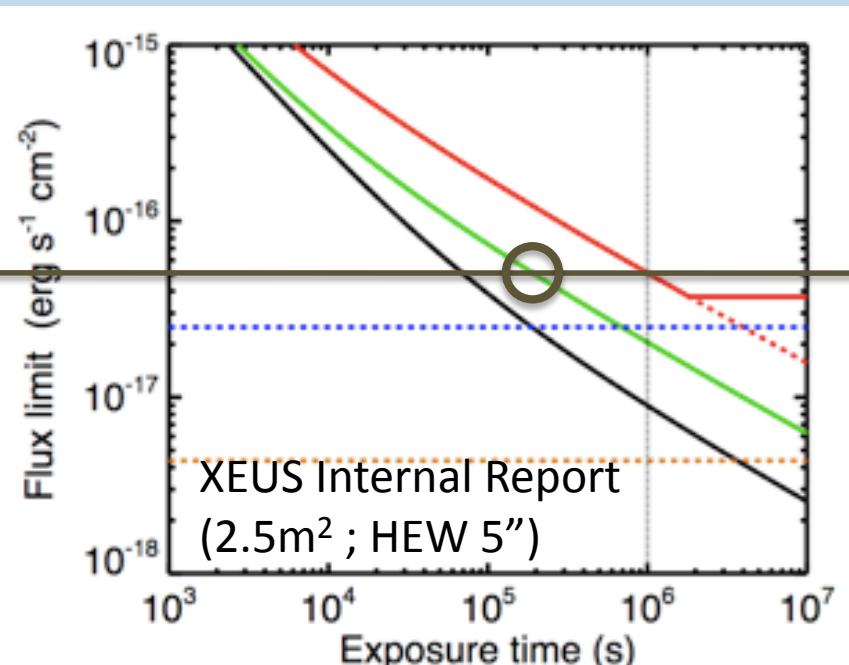
- 1) Intrinsic $L_x = 10^{28.0}$ erg/s with $A_V = 10$ mag
- 2) Intrinsic $L_x = 10^{27.8}$ erg/s with $A_V = 5$ mag

@ 450 pc

$$(f_x)_{\text{abs}} \sim 5 \cdot 10^{-17} \text{ erg/cm}^2/\text{s}$$

@ 0.5-2 keV for $kT = 1$ keV

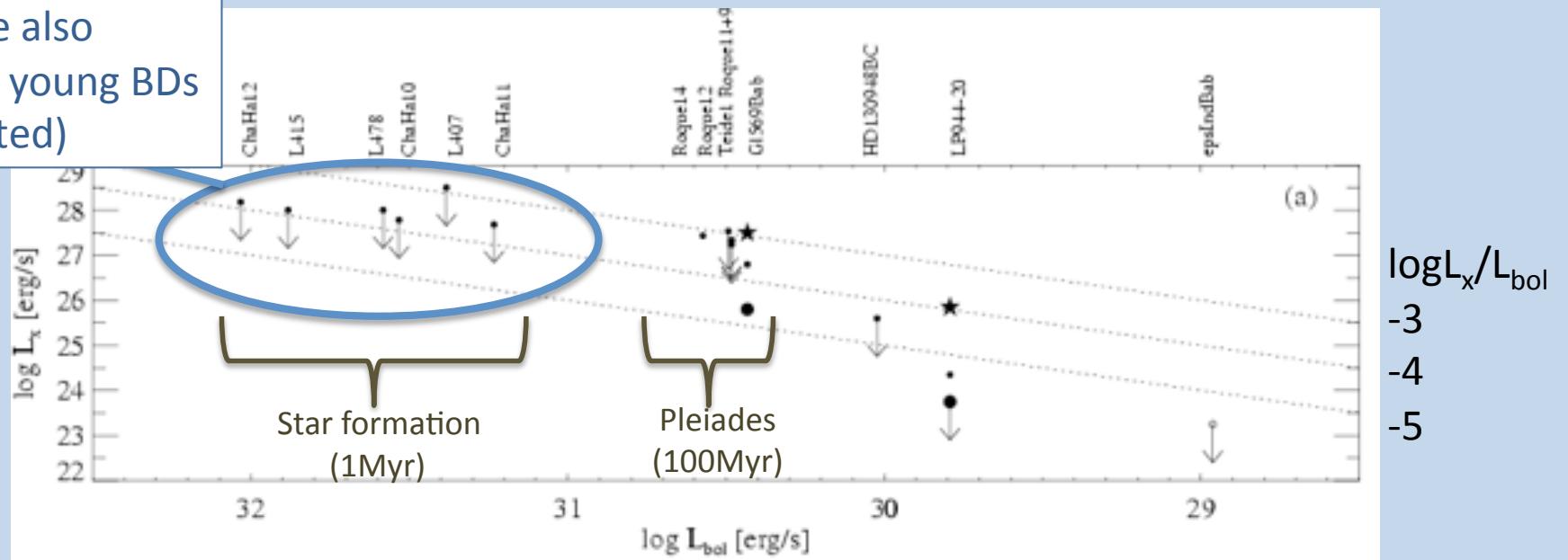
IXO/WFI: detects these objects in ~200 ks



XEUS Internal Report
(2.5m^2 ; HEW 5'')

Brown dwarfs: Evolution of the dynamo in the substellar regime ?

There are also
detected young BDs
(not plotted)

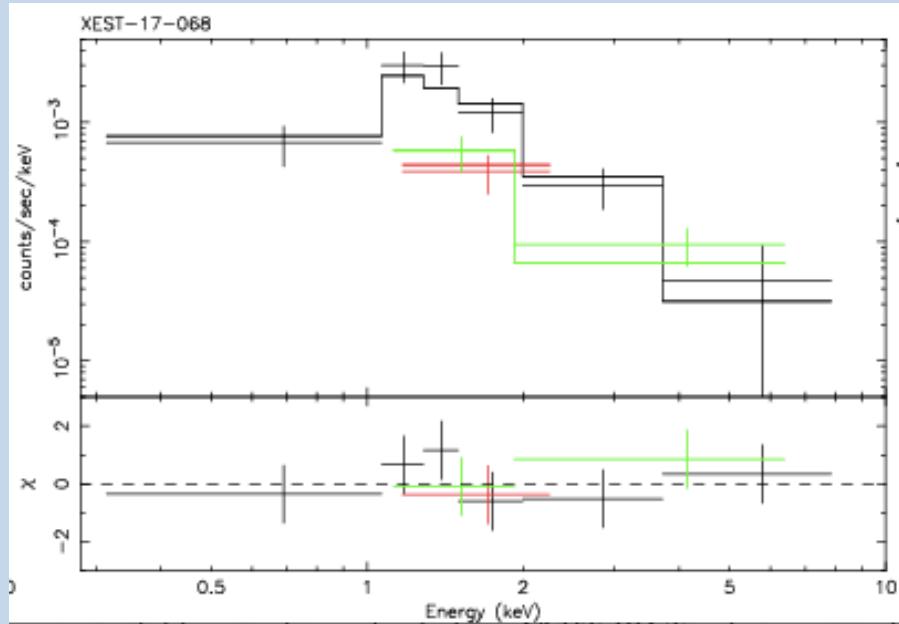


Stelzer et al. (2006)

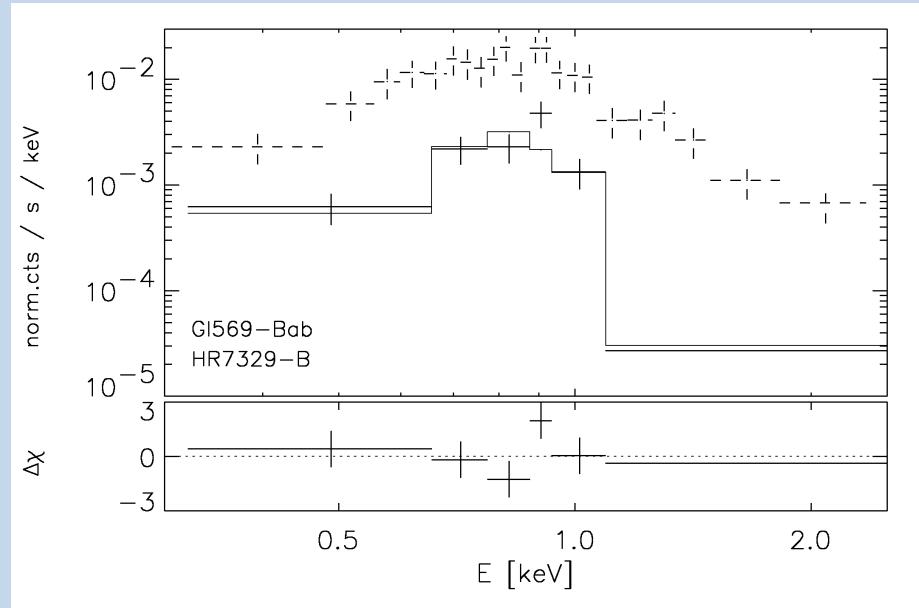
- L_x / L_{bol} decreases with age and/or T_{eff}
Interpretation: increasingly neutral atmosphere -> poor coupling matter/magn.field
- Only 1 L dwarf detected in X-rays so far (Audard et al 2007)
- Evolved BDs may have $L_x \sim 10^{25}$ erg/s

IXO/WFI: detects these objects in ~ 20 ksec out to ~ 20 pc
incl. ~ 100 L dwarfs + many late-M dwarfs

Brown dwarfs: Evolution of the dynamo in the substellar regime ?



Grosso et al. (2007)

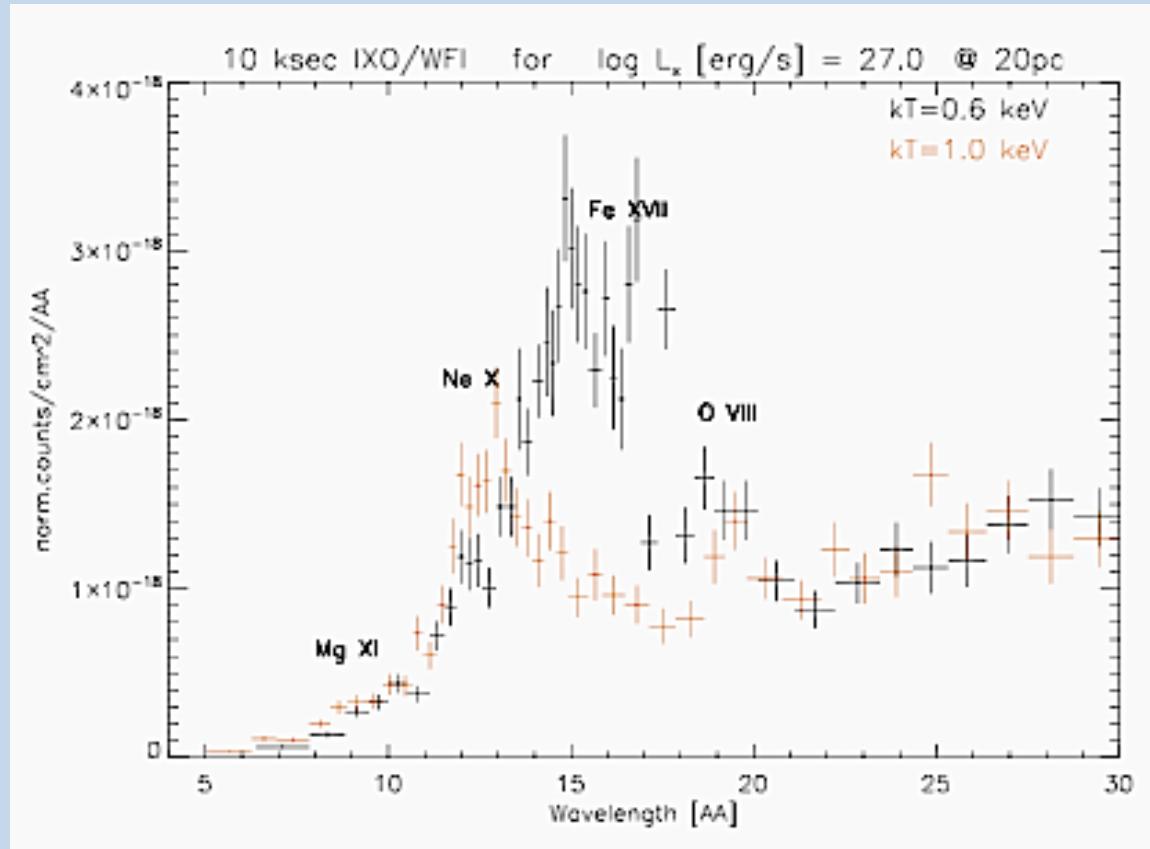


Stelzer et al. (2006a)

	2 Myr (Taurus)	10 Myr	100 Myr
	XEST-17-068	HR7329B	GI569B
T [MK]	20	6	7 (in flare)

There are no good X-ray spectra of brown dwarfs as yet !

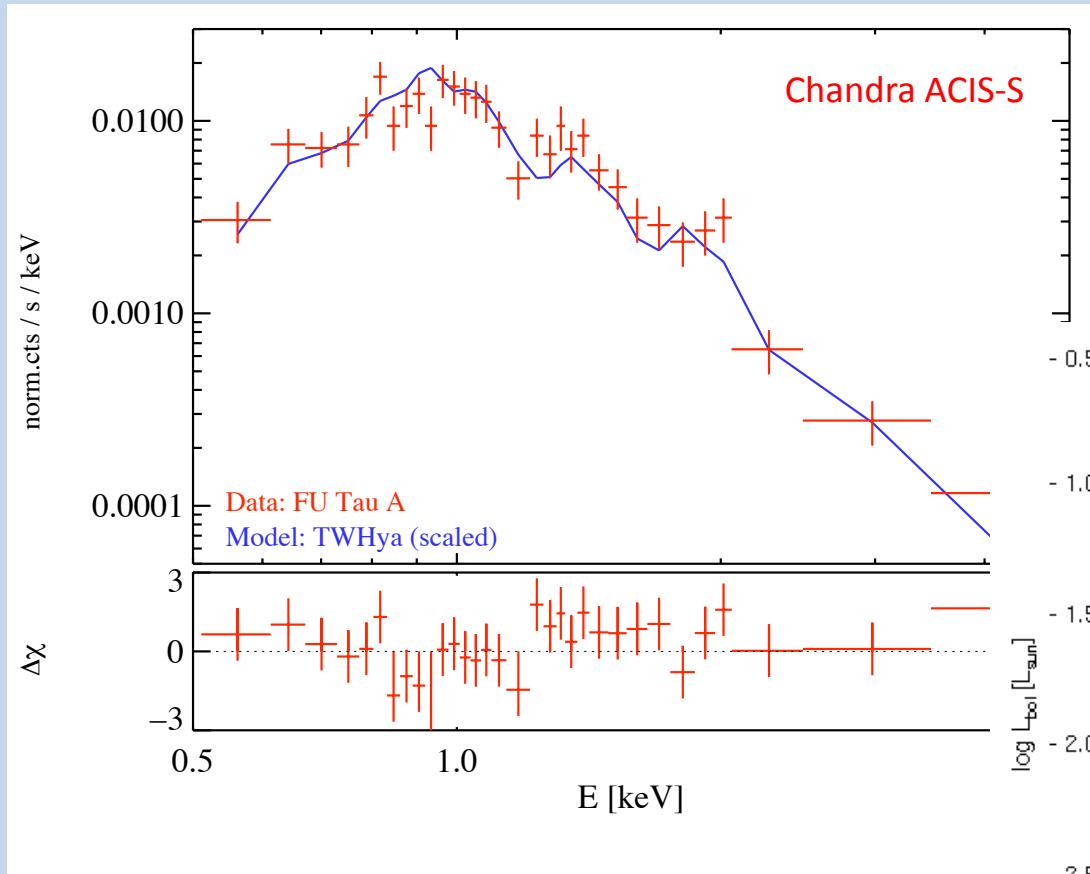
Brown dwarf spectra with IXO/WFI



X-ray temperature can be constrained for nearby BDs in
few ksec for bright (<100Myr);
in ~ 100 ksec for faint (~ 500Myr)

IXO/WFI can verify/refute dependence of X-ray spectrum on age in brown dwarfs.

Brown dwarfs: X-rays from accretion shocks?

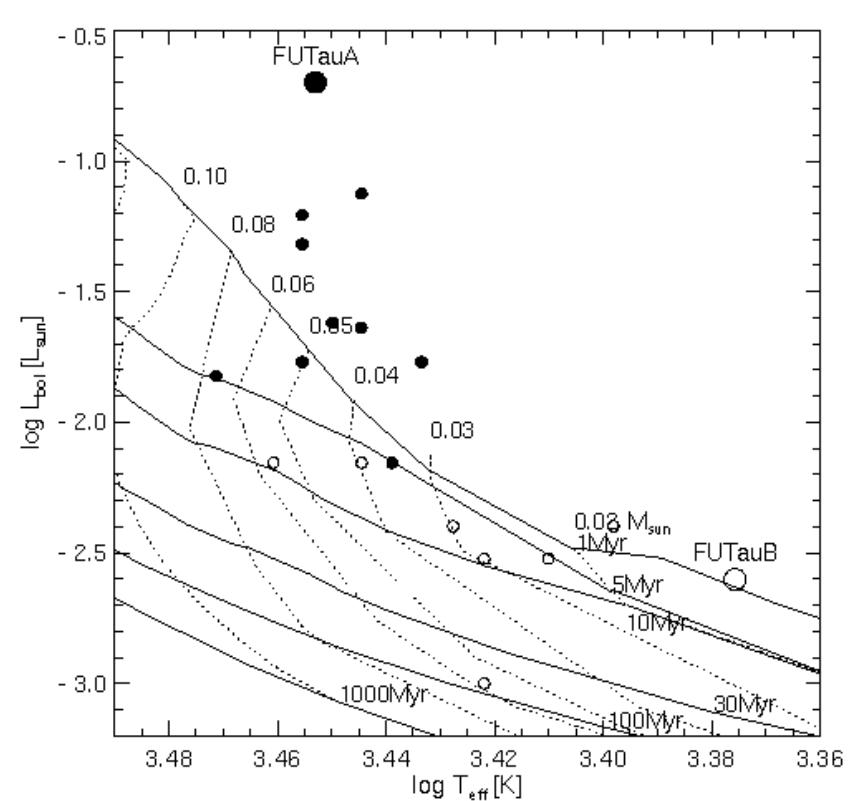


Stelzer et al., MNRAS submitted

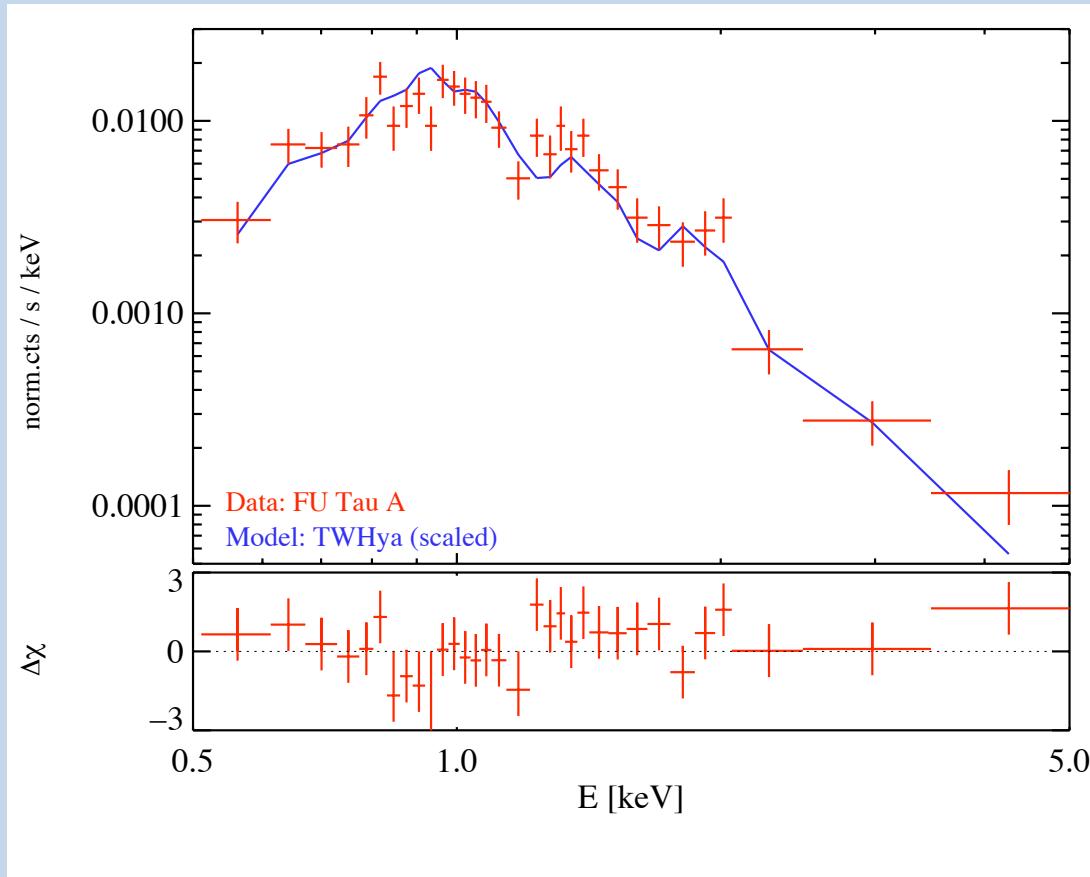
FUTauA is „peculiar“:
far above the evolutionary models in the HR diagram

→ Extreme youth or strong accretion ?

Highest quality X-ray data
for a BD so far:
~ 600 cts for FUTauA



Brown dwarfs: X-rays from accretion shocks?



Stelzer et al., MNRAS submitted

Highest quality X-ray data
for a BD so far:
~ 600 cts for FUTauA

→ Untypically low
temperature (0.24 keV);
as in the prototype
accreting TTS TW Hya !

X-rays from accretion
diagnosed by

1) Soft spectrum

$$T_{\text{psh}} = \frac{3}{16} \frac{\mu m_p}{k_B} v_0^2$$

2) High density

IXO/WFI can sample statistical numbers of low-resolution spectra for BDs
to determine X-ray temperature.

Stellar science with IXO

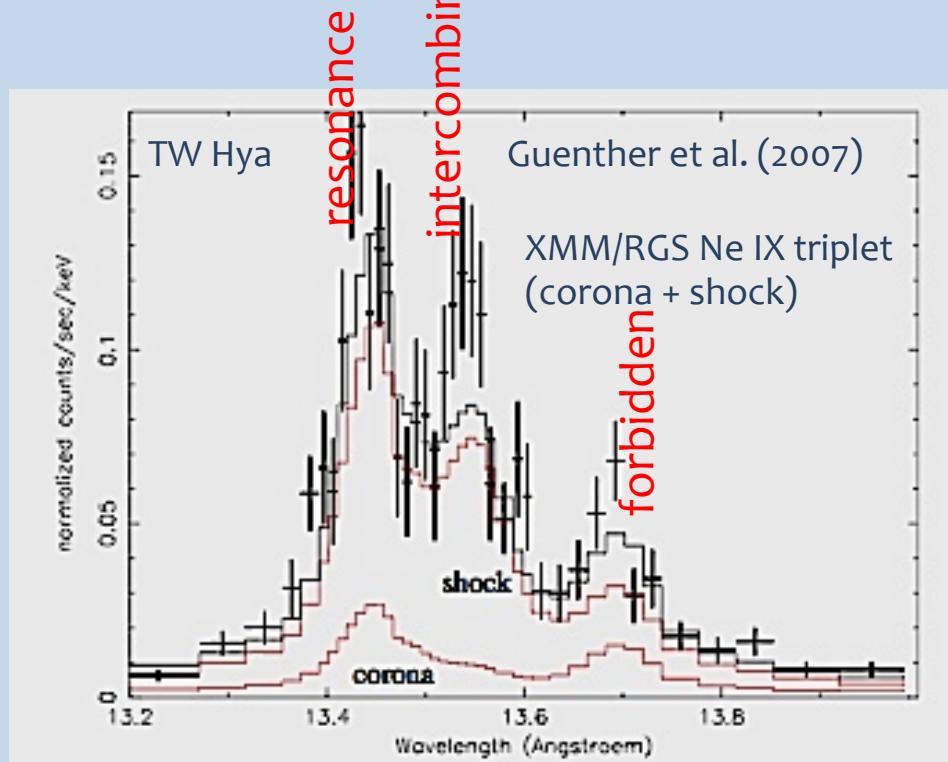
Topics of this talk:

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- **Accretion onto young stars (+ brown dwarfs)**
- Nature of the Fe K α emission in pre-main sequence stars

High-resolution X-ray spectroscopy: Densities from He-like triplets

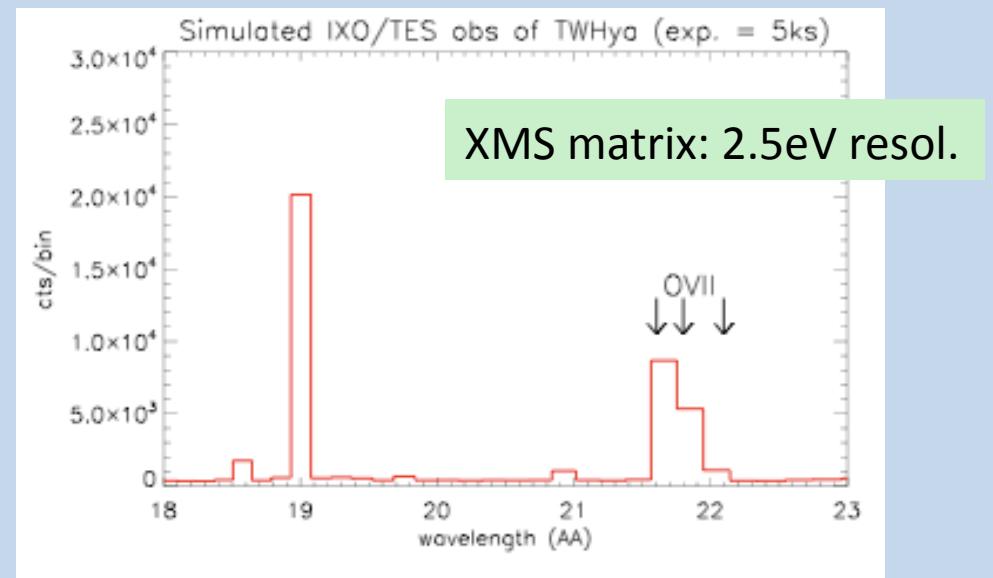
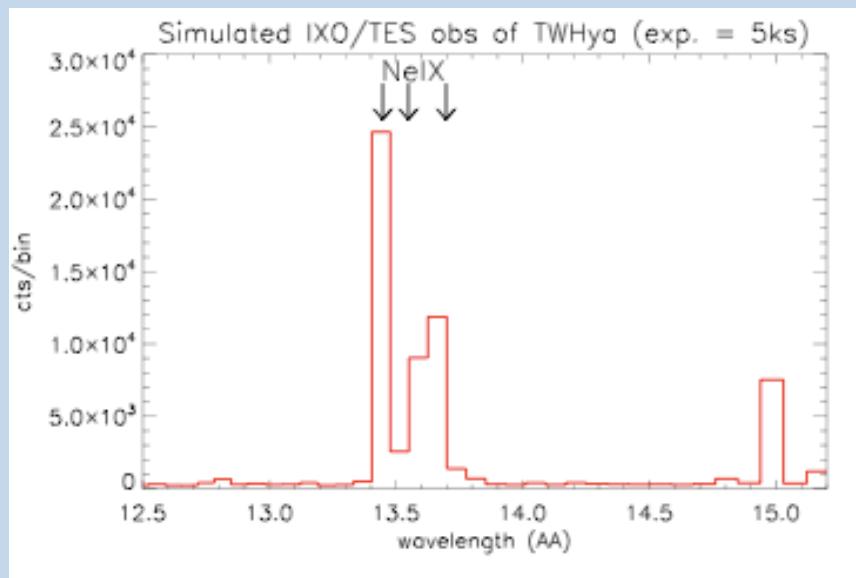
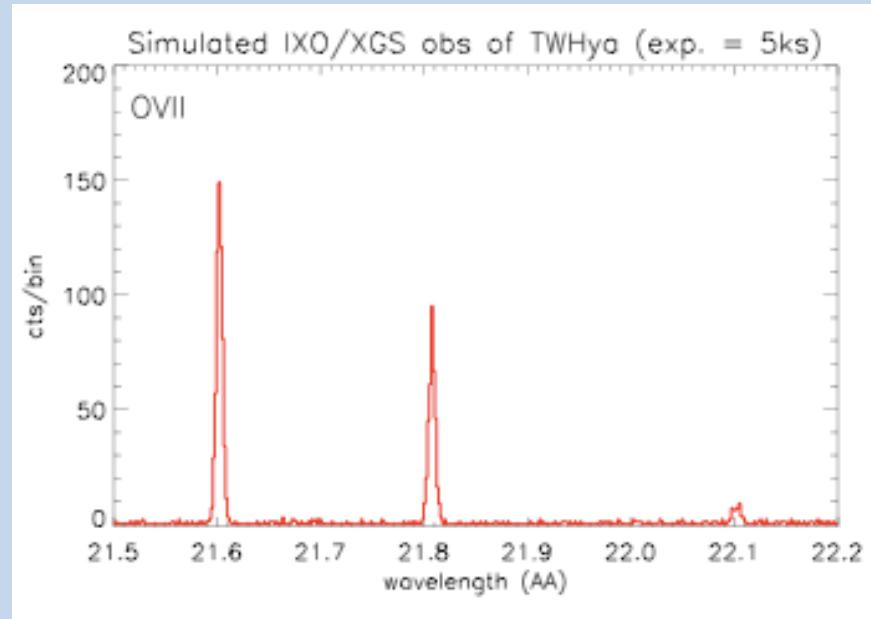
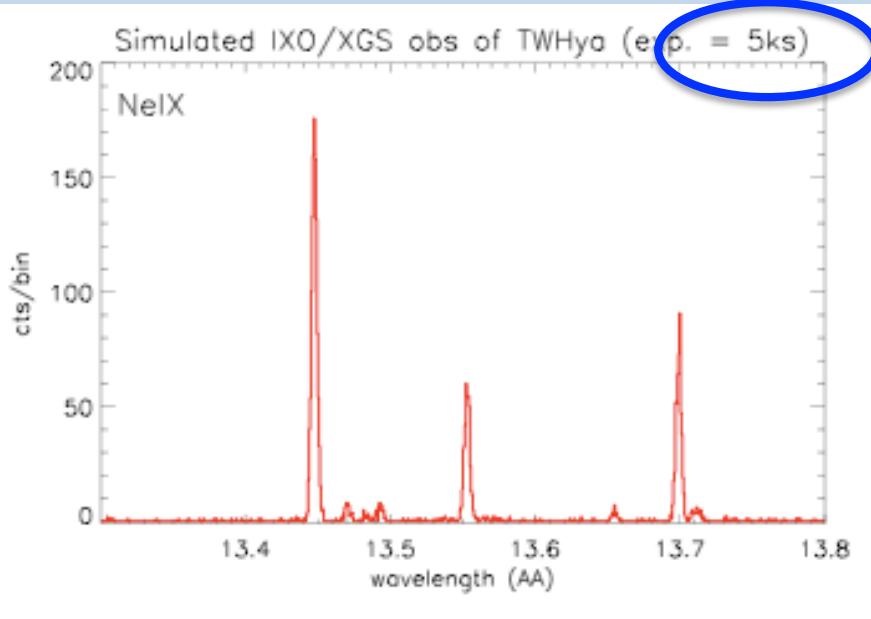
- Diagnostic for accretion shock: high-density ($\sim 10^{12} \text{ cm}^{-3}$)
(vs. low-density corona $\sim 10^{10} \text{ cm}^{-3}$)

→ line diagnostics, He-like triplets: low f/i flux ratio indicates high n_e

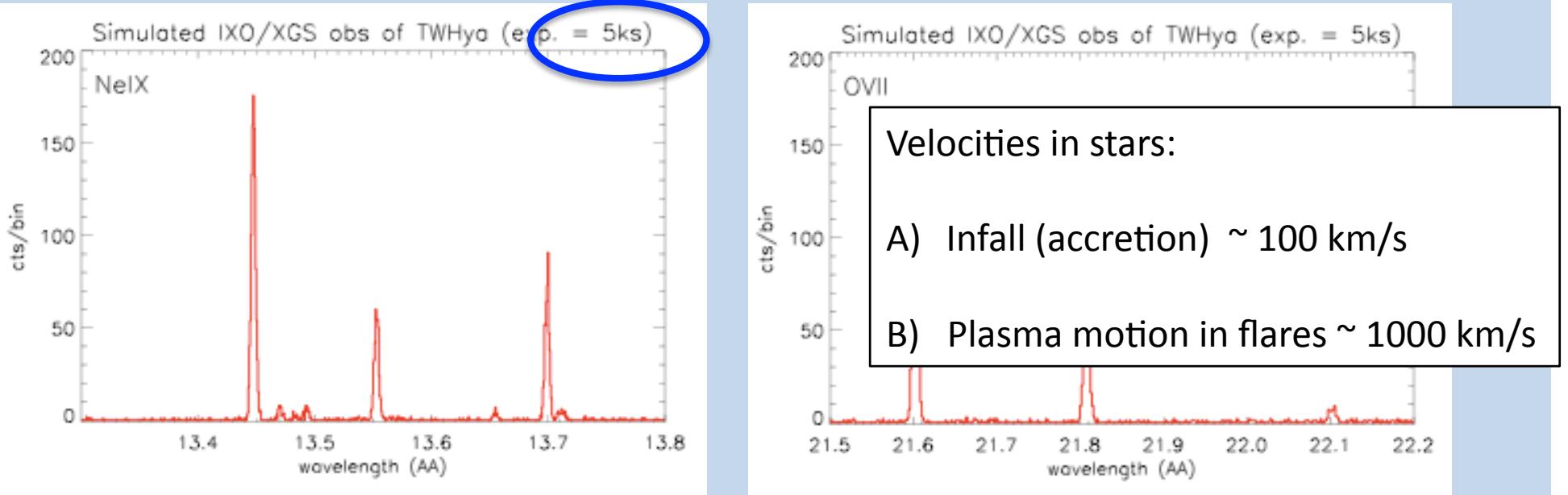


Only 7 cTTS bright enough
for XMM/Chandra gratings.

High-resolution spectra of T Tauri stars with IXO



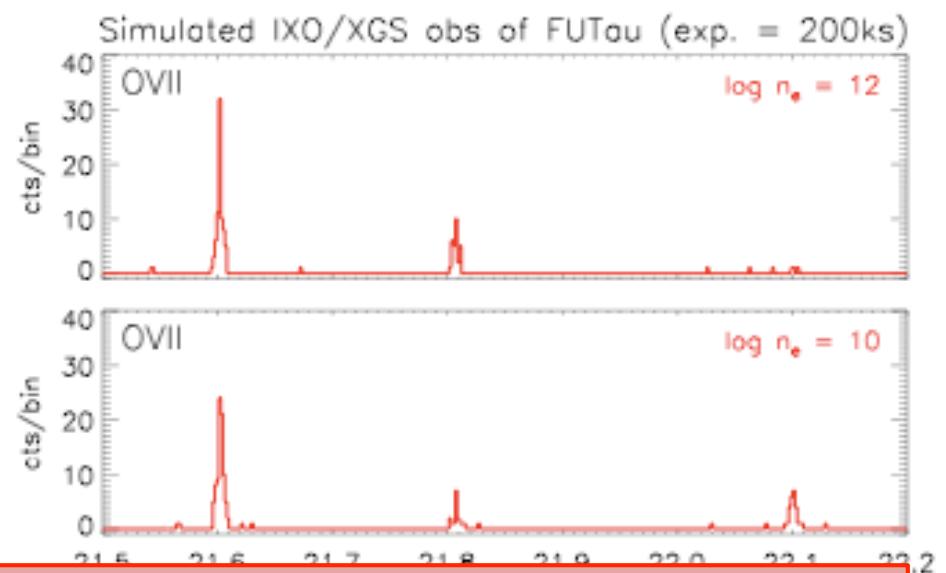
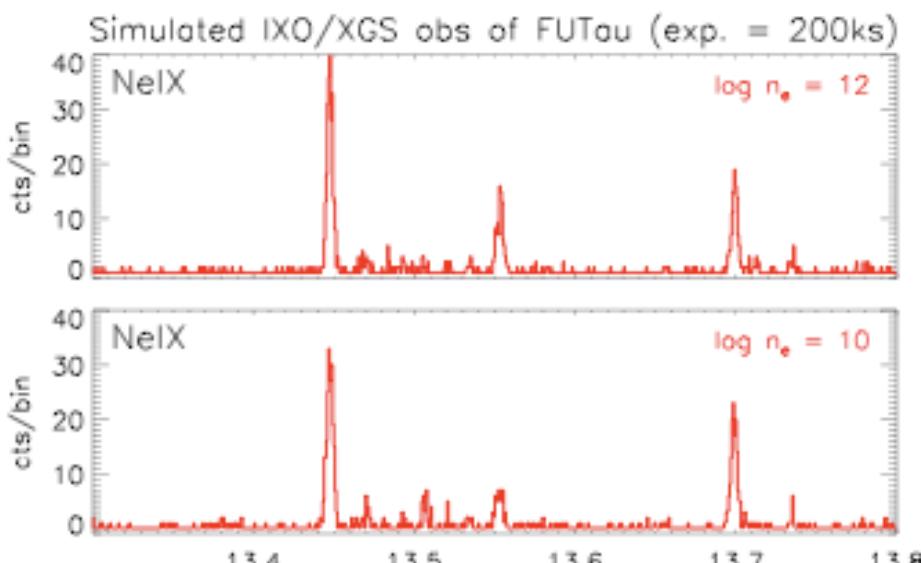
High-resolution spectra of T Tauri stars with IXO



IXO/XGS(+XMS) potential:

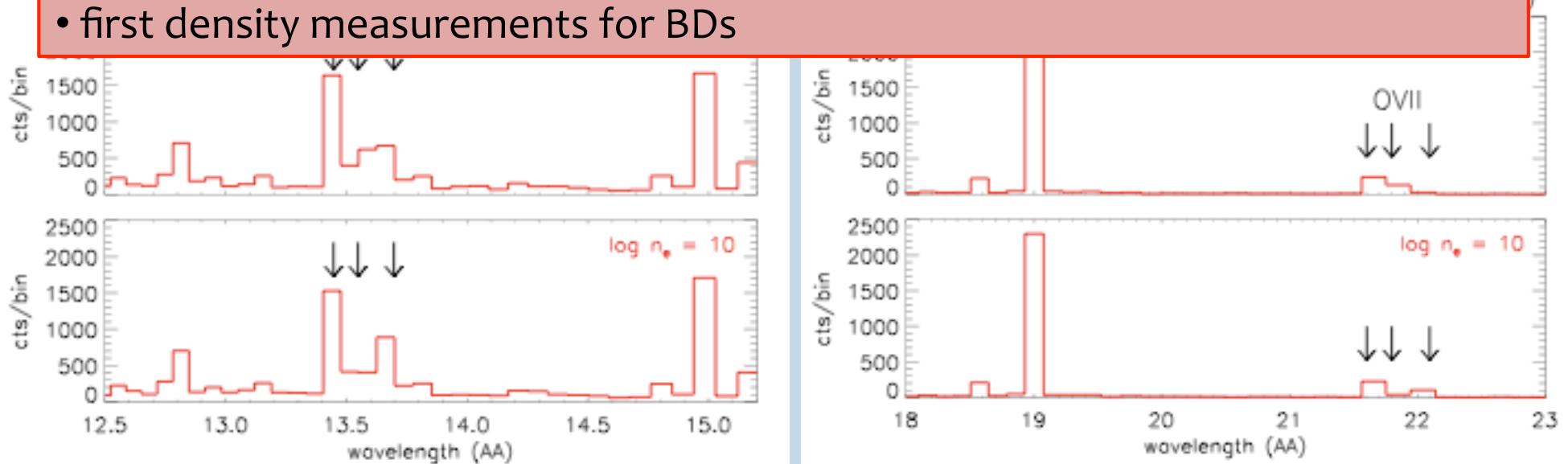
- good S/N spectra in < 100ksec for TTS up to 500 pc (Taurus, Cha, Orion, etc)
→ n_e in cTTS → accretion vs. corona
- time-resolved high-resolution spectroscopy (~10ksec expo. for bright TTS)
→ n_e variations probing accretion structure
→ n_e variations in stellar flares
- line shifts w.r.t. v_{rad} : $\Delta v = \sigma/N^{1/2} = (\text{FWHM}/2.35)/N^{1/2} = \dots \sim 10$ km/s
for FWHM = $\Delta\lambda = 3000/\lambda$ and $N \sim 100$

High-resolution spectra of brown dwarfs with IXO



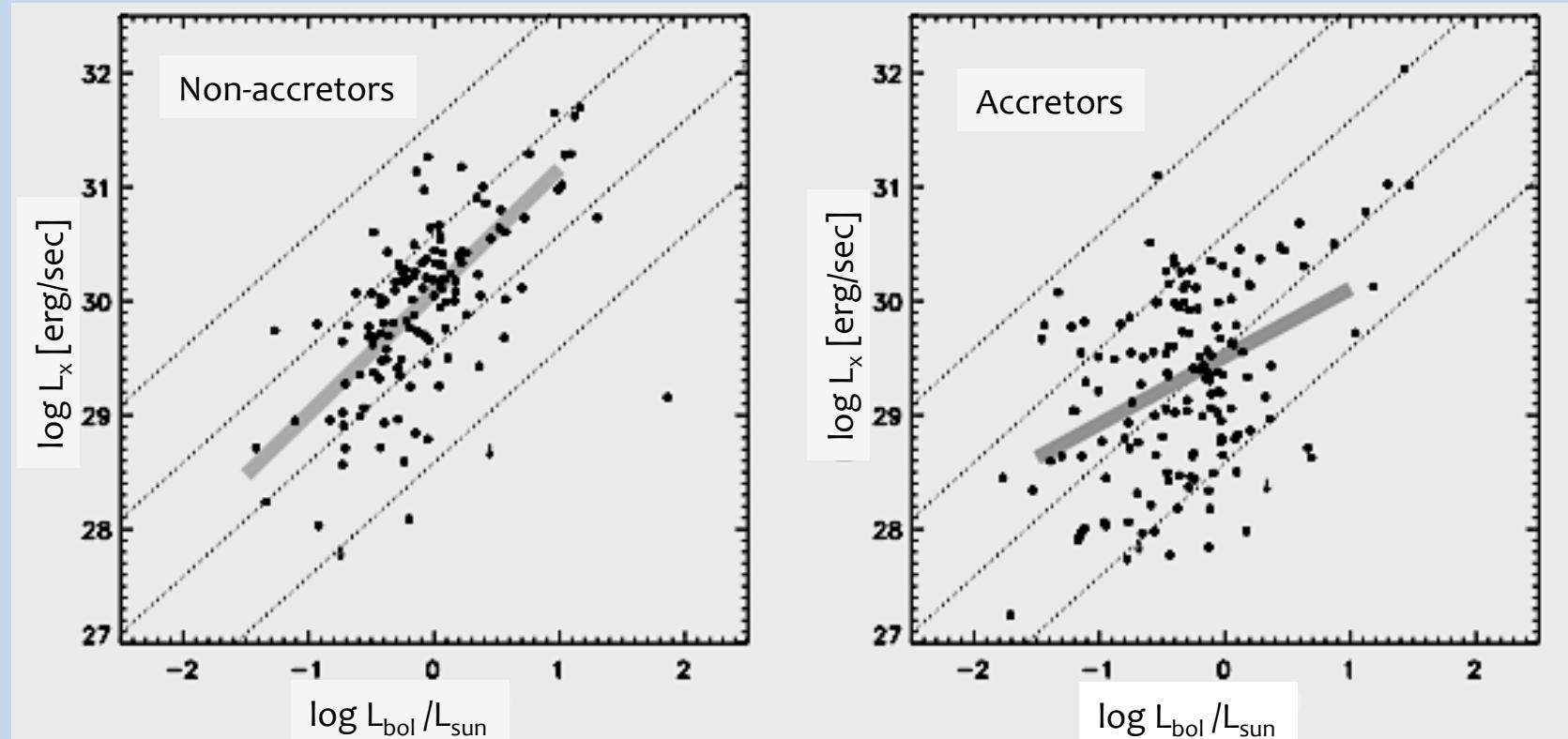
IXO/XGS(+XMS) potential:

- first density measurements for BDs



Time-resolved spectroscopy of pre-MS stars: probing the accretion structure

COUP (= Chandra Orion Ultradeep Project) 850 ks Chandra



Preibisch et al. (2005a)

Accretors have lower L_x than non-accretors.

Possible explanation:

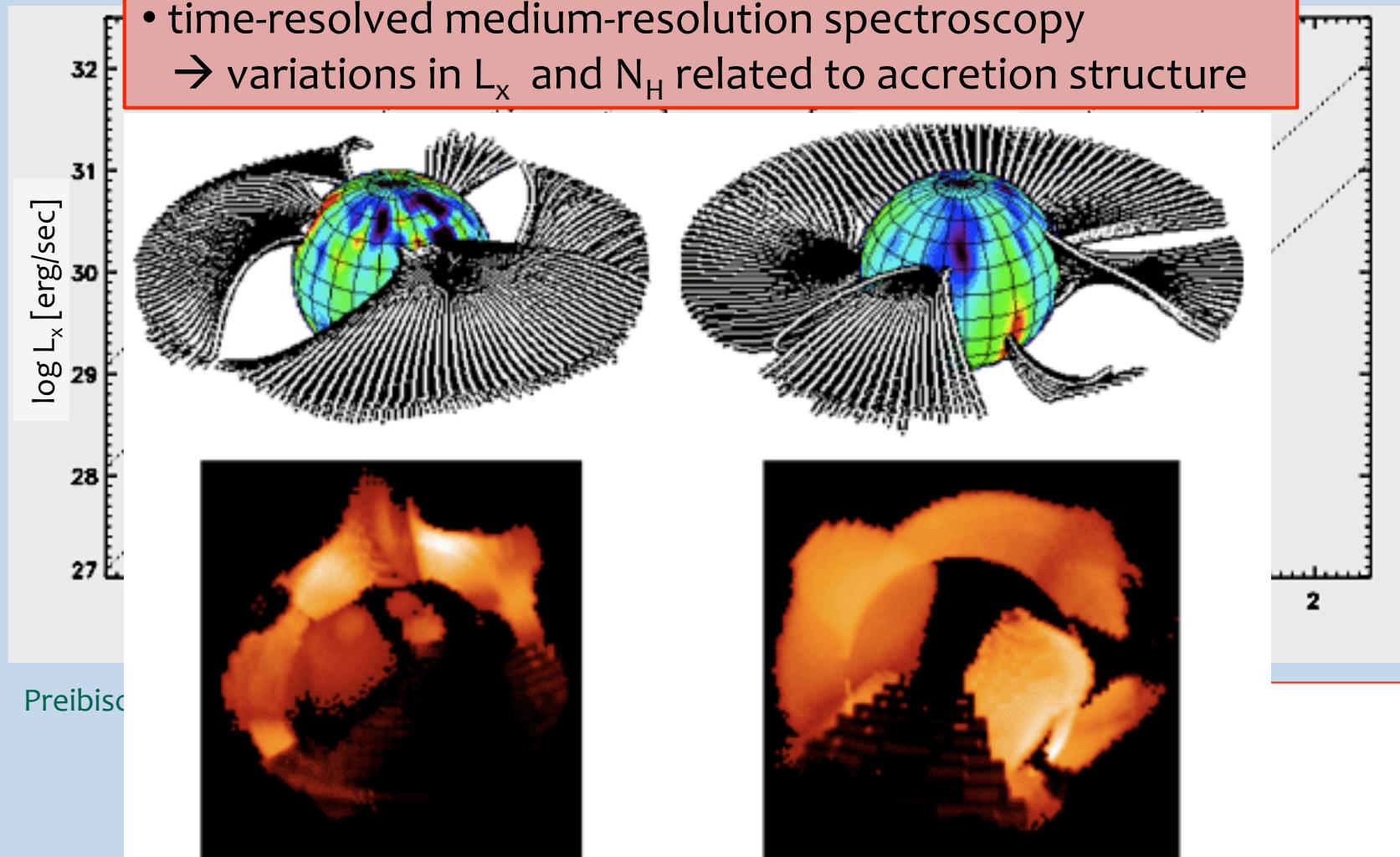
- A) Higher density \rightarrow less efficient heating
- B) Less efficient convection \rightarrow weaker dynamo
- C) X-ray emission obscured by accretion streams (Gregory et al. 2007)

Time-resolved spectroscopy of pre-MS stars: probing the accretion structure

COURT

IXO/WFI potential:

- time-resolved medium-resolution spectroscopy
→ variations in L_x and N_H related to accretion structure



Preibisch

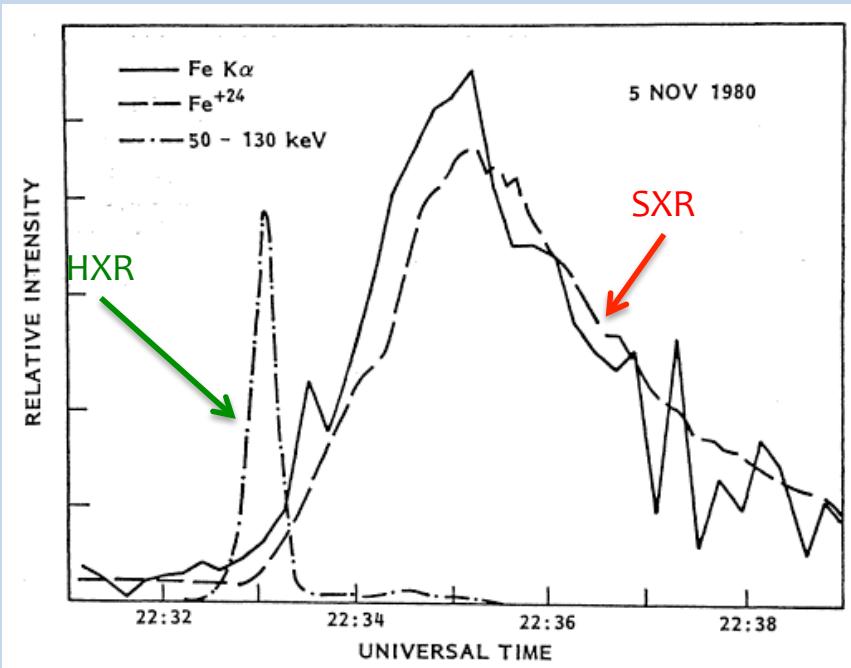
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Stellar science with IXO

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- **Nature of the Fe K α emission in pre-main sequence stars**

Fe K α emission from the Sun

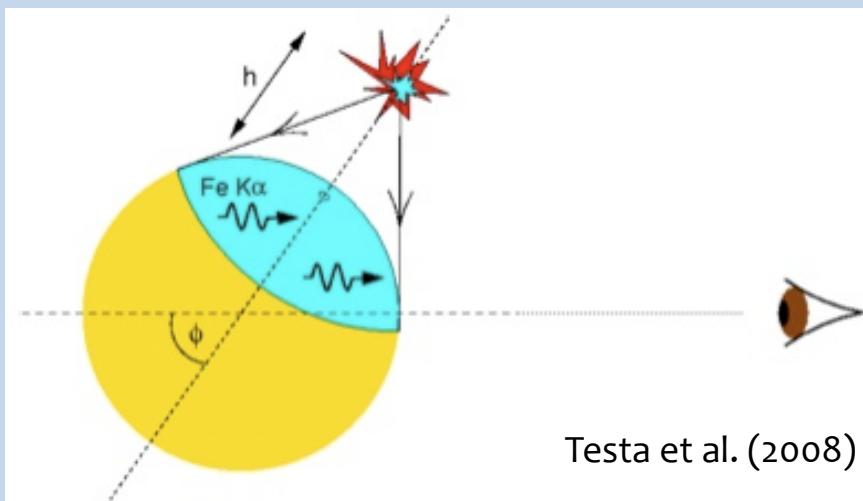


Culhane et al. (1981)

Sun:

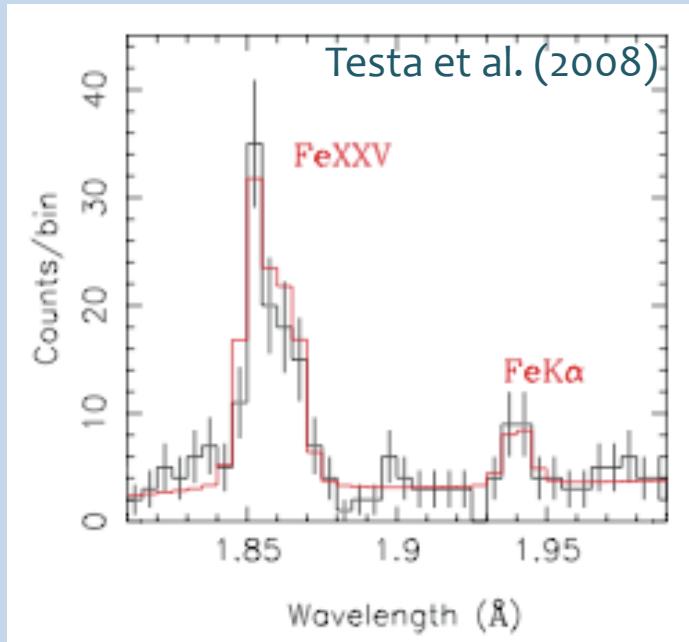
6.4 keV K α line
during gradual phase of flare
(similar to soft thermal X-rays;
unlike hard non-thermal X-rays)

→ fluorescence of photosphere
illuminated by X-rays



Testa et al. (2008)

Fe K α emission from normal stars: Fluorescence \rightarrow flare location

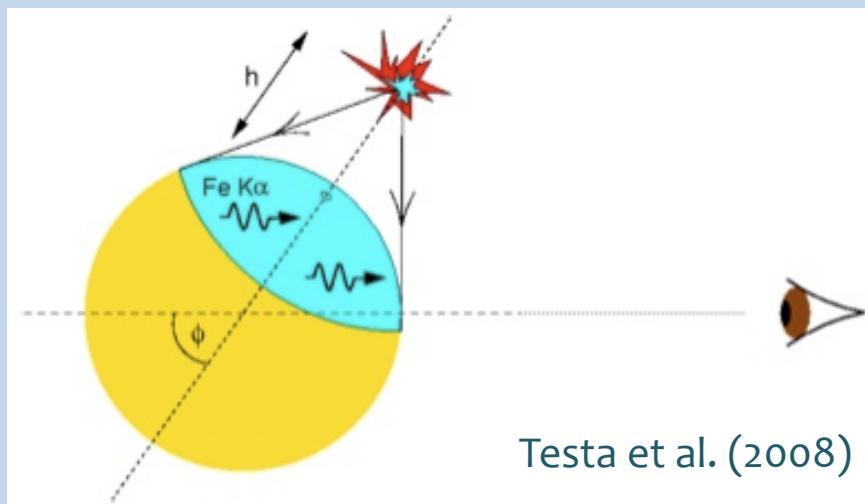


HR9024 (G giant)

6.4 keV K α line
during initial phase of flare

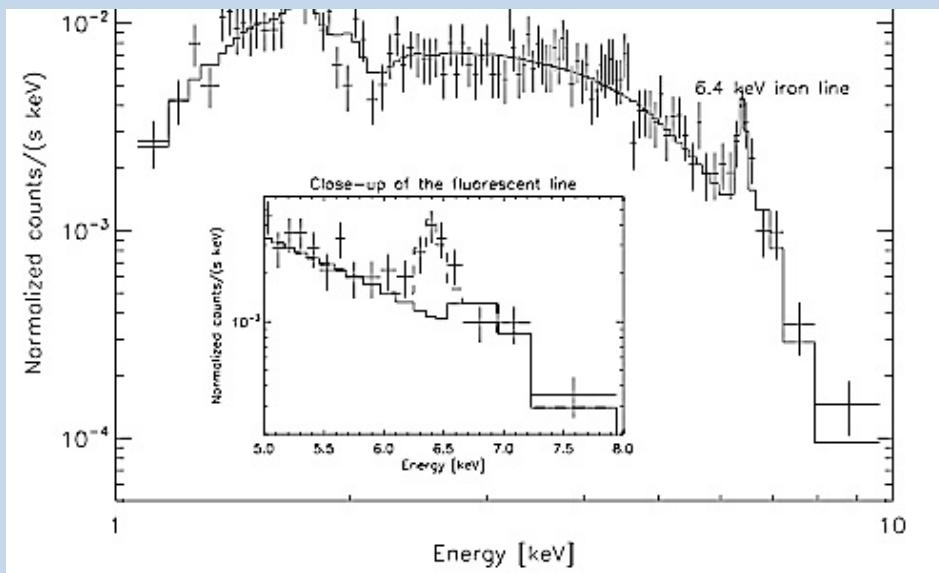
photospheric fluorescence model
constrains flare height: $\sim 0.1 R_*$

see also Osten et al. (2007)



In pre-MS stars
Fe K α emission comes from disk
(e.g. Tsujimoto et al. 2005)

Fe K α emission from pre-MS stars: fluorescence or e $^-$ impact ionization ?

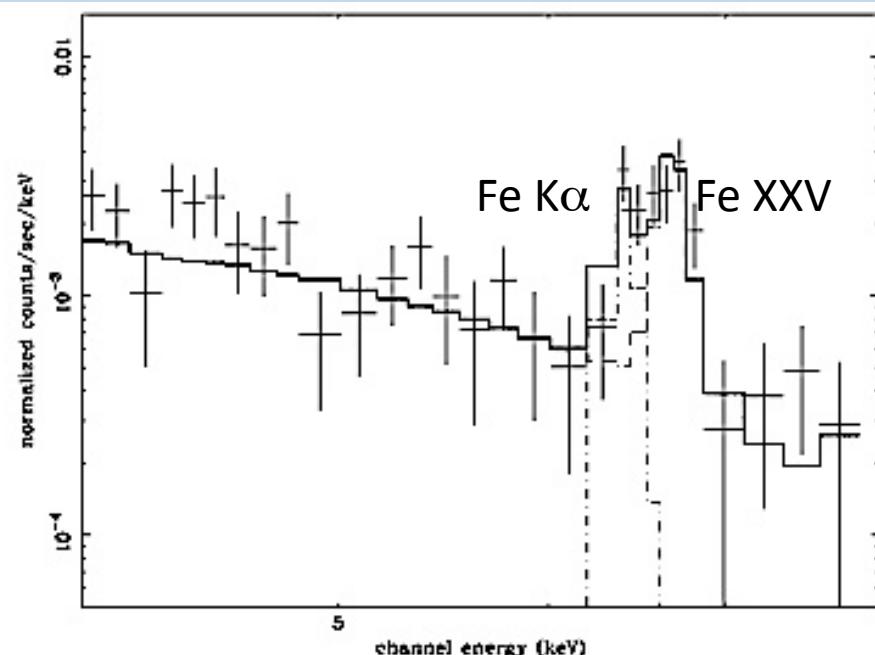


V1486Ori (COUP #331)
– Czesla & Schmitt (2007)

No 6.7keV line (very hot plasma; > 10 keV)

Very strong 6.4keV line ($W \sim 1400$ eV)
for short time during flare rise

fluorescence calculations underpredict
observed K α flux

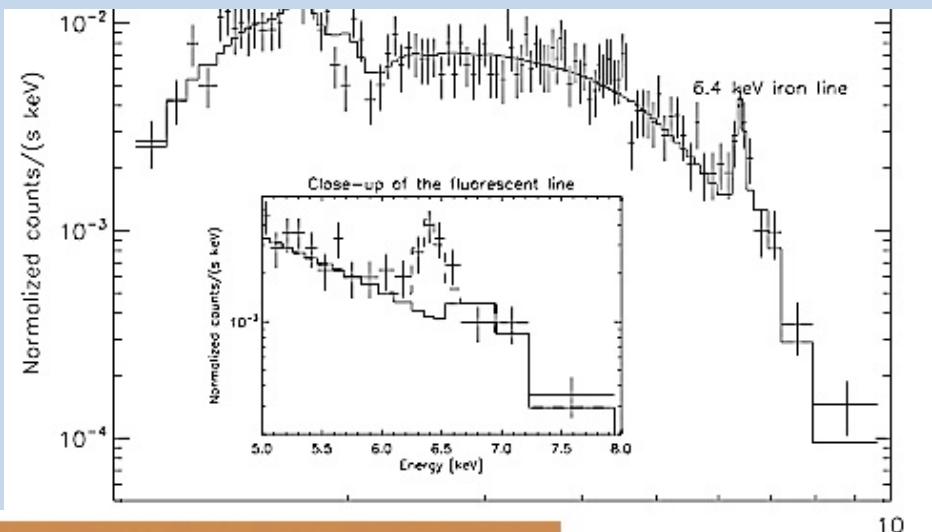


Elias 29 (DROXO)
– Giardino et al. (2007):

6.4keV line
in quiescent phase after a flare

sustained ionization mechanism
independent of X-rays;
coll. Ionization by non-thermal
electrons in star-disk loops

Fe K α emission from pre-MS stars: fluorescence or e $^-$ impact ionization ?



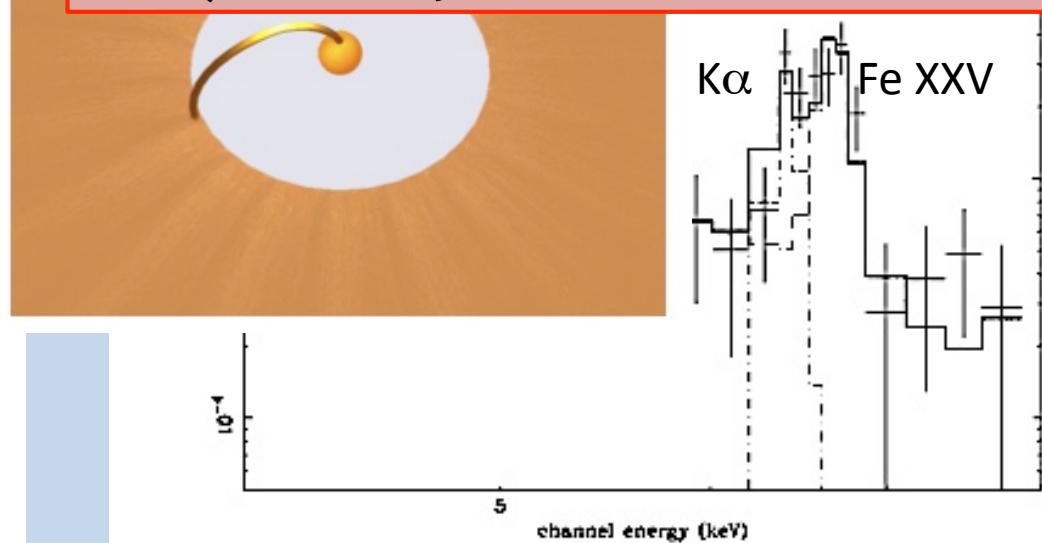
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IXO: Reverberation mapping reveals geometry of system
(time-delays continuum vs. line emission)



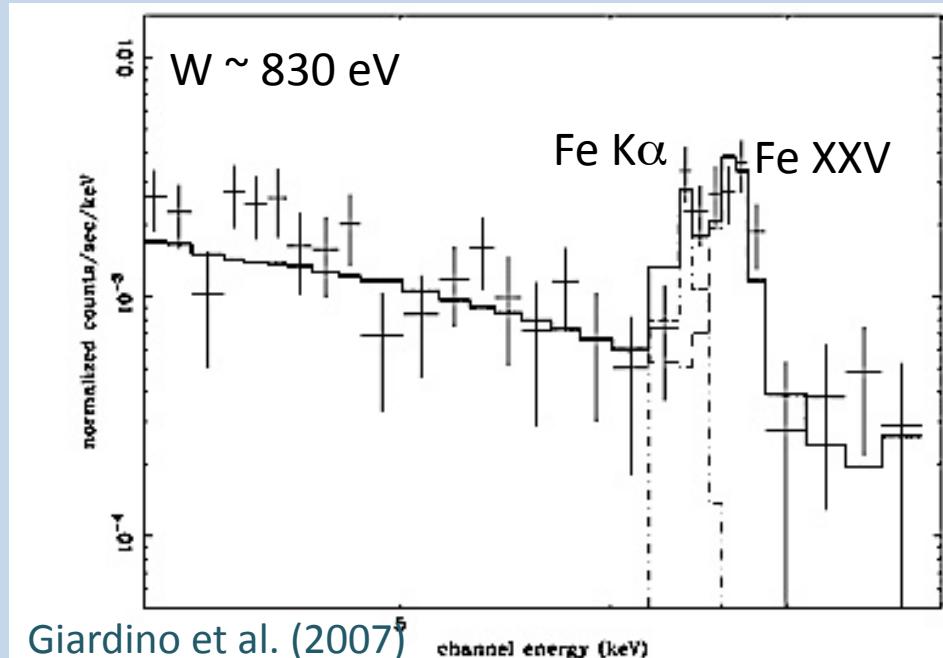
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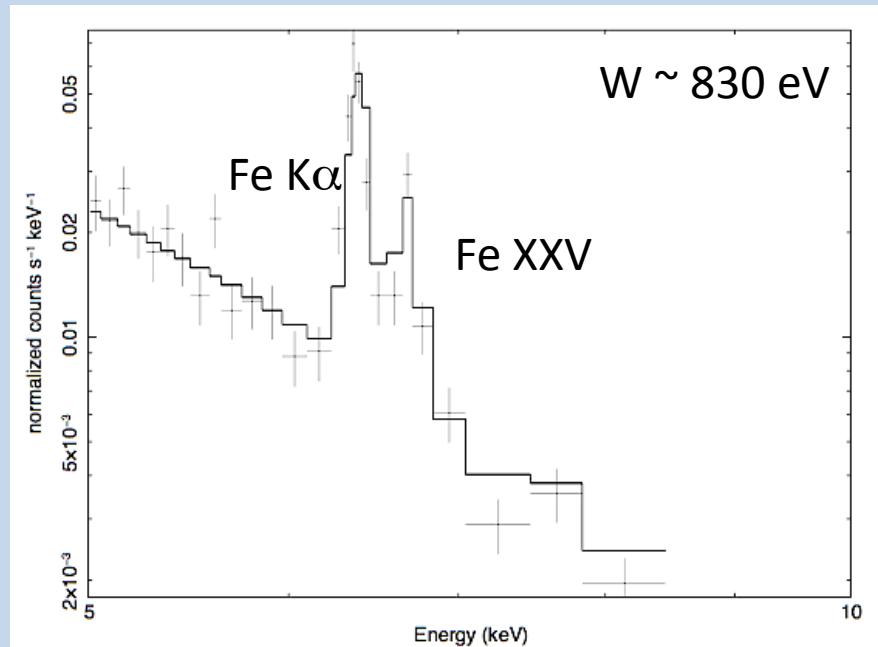
Fe K α emission with IXO/WFI

85 ksec XMM/pn



Giardino et al. (2007)

25 ksec IXO/WFI



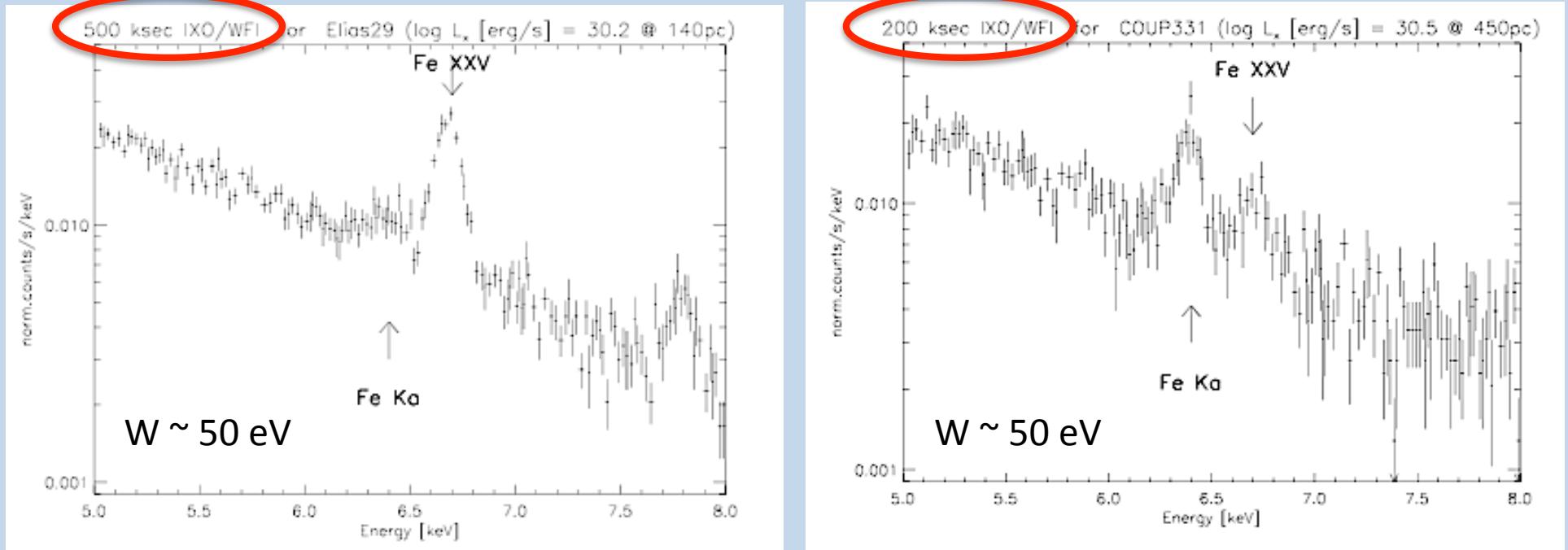
IXO/WFI + XMS:

- time-resolved Fe K α spectroscopy:
detecting time-delay between flare and appearance of Fe K α line from disk

USE OF WFI ?

- 1) HXI: good constraint on high-energy (>7.1 keV) continuum
- 2) large FOV \rightarrow several stars in 1 field (dependence of Fe K α on evol. state)

Fe K α emission with IXO/WFI



Detection of weak Fe K α depends on spectral shape of continuum!

IXO/WFI + XMS:

- detect photospheric Fe K α fluorescence ($W_{H\alpha} \sim 50$ eV in few 100 ksec): modeling photospheric fluorescence efficiency

Origin of the X-ray emission from Brown Dwarfs

- L_x / L_{bol} ratio of *young* BDs as in T Tauri stars?
- Age evolution of BD X-ray emission level?
- X-ray emission mechanisms (accretion?)

Densities with high-resolution spectra

- accretion vs. coronal X-rays in many T Tauri stars and BDs
- time-variations of accretion process and flare plasma

Time-resolved spectroscopy

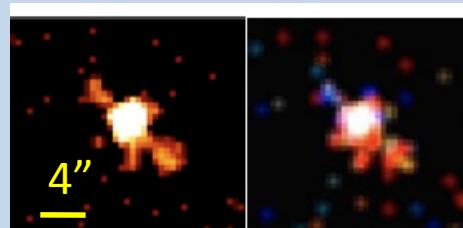
- Origin of Fe K α emission: fluorescence? Electron impact ionization?
- Orbital and rotational modulations in colliding wind binaries, magn.confined winds, magn.active regions on cool stars...
- Flare dynamics

Stellar science with IXO

Some topics not discussed in this talk:

- Stars with faint (or no?) X-ray emission:

0.6-1.7 keV ACIS-S: DG Tau + jets



Guedel et al. (2008)

Class 0 protostars WR-stars

(X-ray emission mechanism unclear)
pre-main sequence jets

IXO/WFI:

high sensitivity + large field
+ high spatial resolution

- hot stars with wind-driven X-rays:

line profiles suggest

'non-canonical' small mass loss rate or wind clumping

IXO/XGS(+XMS):

high sensitivity + spectral resolution

Poster: Osokinova

- rotational + orbital modulations in ...

...colliding wind binaries, magn.confined wind shocks,
active regions on cool stars

IXO/WFI + XMS:

Time-resolved spectroscopy

Poster: Rauw
Iping

- flare evolution: e.g. resolving the short rise phase of flares

Poster: Huenemoerder